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**MECHANICAL CHARACTERISTICS
OF STABILITY-BLEED VALVES
FOR A SUPERSONIC INLET**

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16. Abstract <p>Mechanical characteristics of a set of direct-operated relief valves used in a throat-bypass stability-bleed system designed for the YF-12 aircraft inlet are described. Data taken before, during, and after the wind-tunnel tests of the throat stability bypass system are presented. Because of practical limitations, the wind-tunnel investigation was not conducted at the temperatures associated with high-Mach-number flight. However, the stability-bleed valves were tested to 700 K during the bench tests. A comparison of data taken before and after the wind-tunnel tests (at room temperature) showed that both the effective spring rate and the piston friction had decreased during the wind-tunnel tests. In neither the effective spring rate nor the piston friction was the magnitude of change great enough to cause significant impairment of overall system effectiveness. No major valve mechanical problems were encountered in any of the tests. During high-temperature bench tests, piston frictional drag increased. The friction returned to its initial room-temperature value when the stability-bleed valve was disassembled and reassembled. The problem might be solved by using a different material for the piston sleeve bearing and the piston rings.</p>					
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MECHANICAL CHARACTERISTICS OF STABILITY-BLEED VALVES FOR A SUPERSONIC INLET

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SUMMARY

The mechanical characteristics of a set of direct-operated, mechanical relief valves used in a throat-bypass stability-bleed system of a mixed-compression inlet are described. The stability-bleed valves are designed to be incorporated within the cowl structure of a modified flight inlet from a YF-12 aircraft. The stability-bleed valves provide large, quick changes in bleed-exit flow area in response to small changes in inlet pressure.

Data taken before, during, and after the wind-tunnel tests of the throat-bypass stability-bleed system are presented. Because of practical limitations, the wind-tunnel investigation was not conducted at the temperatures associated with high-Mach-number flight. However, the stability-bleed valves were tested to 700 K during bench tests.

The stability-bleed valves did not display any fundamental mechanical problems. A comparison of data taken at room temperature before and after the wind-tunnel tests (conducted at 395 K) showed that the effective spring rate and the piston friction had decreased by 20 and 25 percent, respectively, during the wind-tunnel tests. However, the stability-bleed valves worked well, and some change in friction is acceptable. If the stability-bleed valves were closed and there were no pressure drop across the pistons, it would take an acceleration of approximately 10 g's in the opening direction to open the stability-bleed valves. If the stability-bleed valves were already open, it would take approximately 5 g's in the closing direction to cause the pistons to start to close. These values exceed the accelerations to which the YF-12 aircraft flight inlets would be expected to be subjected from either random vibration or maneuvers.

One concern is the increase in piston frictional drag discovered during high-temperature bench tests. After the disassembly and reassembly of the valve, the frictional drag returned to its initial room-temperature value. The problem might be solved by using a different material for the piston sleeve bearing and the piston rings.

Other comments and recommendations for improving the stability-bleed valve and throat-bypass stability-bleed system reliability for future applications are presented.

INTRODUCTION

Efficient operation of a mixed-compression inlet is achieved when the normal shock is just aft of the throat. In this condition, the inlet can be unstalled by a small disturbance. The inlet is stabilized against changes in upstream and downstream conditions by the action of its bleed systems and its actively controlled variable geometry. Flight-weight active control systems do not provide fast-acting responses, and they can be unreliable in a high-Mach-number environment. Bleed systems can provide fast flow changes. But a high-capacity, fixed-exit bleed permits continuously excessive bleed flow at design conditions, which penalizes inlet efficiency. A recent study at the NASA Lewis Research Center (refs. 1 and 2) has shown that a bleed system using mechanical valves can provide large, stabilizing flows quickly and can maintain low bleed at design conditions. The previously tested system required a separate variable reference pressure, under manual control. Also, the valve mechanization was not compatible with high-temperature operation or with integration into the inlet structure.

In a continuation of the investigation of mechanical bleed valves, the Lockheed Aircraft Corporation and the Cadillac Controls Company, under a NASA contract, have designed and built a set of environmentally tolerant stability-bleed valves that are suitable for incorporation into the cowl structure of a modified flight inlet of a YF-12 aircraft. This design was based on a feasibility study (ref. 3) conducted by Lockheed Aircraft Corporation. Stability and response characteristics of the stability-bleed valve design were established by an analog computer study (ref. 4) conducted at NASA Lewis Research Center. Bench testing of a prototype stability-bleed valve for leakage, friction, and wear both at room temperature and at elevated temperatures (ref. 5) was conducted by Cadillac Controls Company. Bench tests of prototype stability-bleed valves for dynamic response at room temperature and at elevated temperatures (refs. 6 and 7) were conducted by Lockheed Aircraft Corporation. Bench tests of prototype stability-bleed valves for stability (ref. 8) were conducted at NASA Lewis Research Center. A YF-12 aircraft flight inlet was modified by incorporating additional cowl bleed holes and 50 of the stability-bleed valves. A wind-tunnel investigation was conducted with this modified inlet in the 10- by 10-Foot Supersonic Wind Tunnel at NASA Lewis. The inlet was subjected to upstream disturbances, which were a combination of Mach-number and angle-of-attack changes, and to downstream airflow disturbances. A considerable improvement in inlet stability was observed without a decrease in steady-state operating efficiency.

An important concern is whether stability-bleed valves that provide large, quick, bleed-exit flow-area changes by responding directly to small pressure changes can operate predictably and reliably. The purpose of this report is to present results from before, during, and after the wind-tunnel program that bear on this question. This report includes a description of the design of the stability-bleed valves and their incorporation

into the inlet structure. Typical transient responses of the throat-bypass stability-bleed system to upstream and downstream disturbances are presented. A detailed presentation is given of the changes in mechanical characteristics of the stability-bleed valves, such as effective spring rate and piston friction. Also discussed are other considerations, such as valve-position sensing and system air-leakage problems. This report, together with the bench-test and valve-design reports, is intended to provide basic information for the design of a suitable throat-bypass stability-bleed system for future use.

U.S. customary units were used in the design of the stability-bleed valves and for recording experimental data. The units were converted to the International System of Units for presentation in this report.

SYMBOLS

g	acceleration of gravity, (cm/sec)/sec
M_0	free-stream Mach number at spike tip
P_{ba}	aft-compartment bleed-plenum total pressure (fig. 4(b)), N/cm ²
P_{bf}	forward-compartment bleed-plenum total pressure (fig. 4(b)), N/cm ²
p_{sd}	cowl sensing-duct static pressure (fig. 4(b)), N/cm ²
p_1, p_2, p_3	cowl static pressures in bleed region (fig. 4(b)), N/cm ²
α_l	local angle of attack at inlet spike tip, deg
β_l	local angle of sideslip at inlet spike tip, deg

APPARATUS

This report deals with the mechanical characteristics of the stability-bleed valve, and only a brief description of the inlet and its installation in the wind tunnel is included herein. Additional information is presented in reference 9.

Inlet and Its Installation in Wind Tunnel

Figure 1 shows a schematic of an unmodified inlet and its cold-pipe assembly for the wind tunnel. An isometric view of the inlet is shown in figure 1(a). The inlet is an axisymmetric, mixed-compression type. It has 60 percent of its supersonic area contraction occurring internally at cruise Mach number. The spike is hydraulically actuated to

translate for restarting the inlet and for off-design inlet operation.

Figure 1(b) is a schematic of the inlet and cold-pipe assembly as tested in the 10- by 10-Foot Supersonic Wind Tunnel. The inlet was mounted on a boiler-plate nacelle, and the entire assembly was mounted on a strut. A 3.05-meter-long cold-pipe assembly was mounted inside the nacelle. The downstream airflow-disturbance generator was mounted inside the cold pipe. The interface between the nacelle and the strut was designed to allow the angle of sideslip to be varied $\pm 3^\circ$ between tunnel runs. The angle of attack of the inlet could be continuously varied between $\pm 6.4^\circ$ during a tunnel run. In the wind tunnel, the inlet was mounted upside down and canted 30° in order to minimize tunnel blockage and maximize angle-of-attack and angle-of-sideslip variations in the inlet assembly.

Airflow-Disturbance Devices

Figure 2 shows the airflow-disturbance devices that were used for the wind-tunnel tests of the stability-bleed system. They created the airflow disturbances that resulted in changes in inlet pressures which actuated the stability-bleed valves.

Figure 2(a) shows the downstream disturbance device. It expands and contracts like an umbrella. The five sliding-plate type valves are independently controlled, hydraulically actuated, position servomechanisms. Flow across the disturbance generator was choked. During startup of the wind tunnel, the disturbance generator was collapsed completely out of the flow stream in order to minimize wind-tunnel blockage. Additional details of the sliding-plate valves and assembly are given in reference 9.

Figure 2(b) shows the upstream airflow-disturbance device. It was mounted on the wind-tunnel floor at the geometric throat of the tunnel nozzle. The plate is hinged and rotates. It is similar to one that was used in the work of reference 10 but has provisions to permit remote operation. The plate is initially held in the vertical position by a latching mechanism. In this position, the plate generates a shock wave that is reflected down the tunnel. When the plate is released, it rotates through a 90° angle because of the aerodynamic loading and changes the reflected shock position and strength. In one test of this airflow-disturbance device, the spike-tip Mach number changed from 2.55 to 2.43, and the spike-tip angle of attack changed from 0° to 1.3° when the plate was dropped. In another test, the Mach number changed from 2.68 to 2.64, and the angle of attack changed from 0° to 0.4° .

Bypass Airflow Systems

Figure 3 is a schematic of the various airflow systems in the YF-12 aircraft flight inlet to which the throat-bypass stability-bleed system was added. Spike boundary-layer

bleed is taken off through a slotted surface on the spike. This bleed is passed overboard through the spike support struts. Cowl boundary-layer bleed is taken off through a shock trap that is a combination of a flush slot and a ram scoop. This flow bypasses the forward-bypass door by means of shock-trap flow tubes. It is then combined with the flow from the aft-bypass door and is exhausted through the engine ejector nozzle. The airflow going through the forward-bypass door is passed overboard. Basically, the spike-bleed and shock-trap airflows are used to improve inlet performance, while the forward- and aft-bypass flows are used to match the inlet airflow to the engine airflow requirements.

Throat-Bypass Stability-Bleed System

Figure 4(a) is a schematic showing the throat-bypass stability-bleed system along with the other inlet-airflow systems. The throat-bypass stability-bleed system improves the capability of the inlet to handle upstream and downstream disturbances without unstarting. Results of a dynamic and a bleed performance study of this throat-bypass stability-bleed system are presented in references 11 to 14.

Figure 4(b) shows details of the throat-bypass stability-bleed system installed in the cowl of the YF-12 aircraft inlet. The stability-bleed valves were located in two circumferential rows of 25 compartments in the cowl, just forward of the shock trap. Figure 4(c) shows the compartment identification numbers. The asterisk denotes compartments that had stability-bleed valves with piston-position transducers. The 50 compartments were isolated from each other by bulkheads. Each compartment housed a self-acting, relief-type, mechanical stability-bleed valve which controlled the bleed-plenum exit area and, hence, the stability-bleed airflow. The forward row of stability-bleed valves compensated for upstream airflow disturbances; the aft row, for downstream disturbances.

That portion of the original, solid, inner wall of the cowl which would have been over the two rows of stability-bleed-valve compartments was replaced with a porous wall. This porous wall had holes normal to the surface. The holes were uniformly spaced at intervals that gave the wall a porosity of 40 percent. In a strip between the two circumferential rows of stability-bleed valves, the perforations were sealed to provide a dividing band of solid wall.

The stability-bleed valves, unlike the ones tested previously (refs. 1 and 2), do not require a reference pressure from a remote source for the pressure on top of the piston. A reference pressure is achieved by using a reference orifice in each piston. This allows the pressure on top of this piston to slowly change until it equals that on the bottom of the piston. The spring preload then is enough to keep the piston closed when the pressure on the bottom of the piston is constant or when it is changing slowly. Thus, the stability-

bleed valves do not open for steady or slowly varying disturbances. The reference orifice diameter (see fig. 4(b)) determines how fast the disturbance must change before the piston will move. The spring plenum of each stability-bleed valve was connected to a separate reference plenum. When the shield was used on the stability-bleed valve, a damping orifice was not needed in the line between the spring plenum and the reference plenum. This was determined during the analog study of reference 4 and was confirmed by the prototype testing reported in reference 8. The aft stability-bleed-valve compartments also had a small, continuous, bleed flow in parallel with the stability-bleed valves as shown in figure 4(b). This bleed was used to pull off part of the cowl boundary layer and resulted in improved inlet flow-pressure characteristics. The amount of this flow to be used was determined during the study reported in references 13 and 14.

The shields and sensing ducts were used so that the pressure under the piston would not be affected by the flow through the bleed plenums. In the case of the aft stability-bleed valves, the sensing duct was placed at the downstream end of the bleed plenum. This location was used because, as the terminal shock moves forward past the sensing tap onto the bleed surface for the aft stability-bleed valves, a higher pressure p_1 is available to actuate the stability-bleed valves. The reason for this is that the static pressure downstream of a terminal shock is higher than the pressure upstream of it. The aft stability-bleed valves provide stability for transient disturbances, usually internal, which cause the terminal shock to move ahead of the shock trap. The forward stability-bleed valves provide stability airflow for transient external disturbances. These disturbances might be changes in Mach number, angle of attack, or temperature. These disturbances create pressure rises on the cowl and spike. The bleed airflow would reduce these pressures to keep the throat from unchoking, thus preventing inlet unstart.

A pressurizing manifold connected to each reference plenum was used to port higher pressure air to the top side of the piston. This pressure could be used to lock the stability-bleed valves closed if necessary during experimental testing. The higher pressure air was obtained from four total-pressure tubes placed near the shock trap in the inlet, as shown in figure 4(b). A check valve allowed the higher pressure air to be ported into the reference plenum but prevented recirculation of air among the individual reference plenums.

STABILITY-BLEED VALVE

Figure 5 shows a cross-sectional view of the stability-bleed valve and a photo of a disassembled valve. The valve is constructed mainly of titanium and weighs about 1 kilogram. The piston is closely guided on the centerpost within the housing. The

clearance around the circumference of the piston is greater, to prevent interference between the piston and the housing. Piston rings, which are made of a carbon compound, are used to minimize the leakage from the spring plenum. A hole drilled in the piston between the two rings connects the volume between the piston and the shield with that between the two rings. This was done to minimize the leakage from the spring plenum to atmosphere. Leakage past the top piston ring is in effect like flow in parallel with the reference orifice which is used to get a desired piston transient response. Thus, by minimizing the leakage from the spring plenum past the top piston ring, the transient response is determined principally by the size of the reference orifice. In the steady state, the pressure on either side of the top piston ring is equal, so there is no leakage from the spring plenum past this ring. Leakage to atmosphere past the bottom piston ring is not as important, because the sensing duct impedance is low and can provide the leakage flow without loss of pressure.

The stability-bleed valve seat was shaped to improve the flow coefficient of the air-flow entering the valve. In an ideal installation, flow coefficients of about 1 could be obtained. But because of the compactness of the valve and bleed system installation in the inlet, flow coefficients near 1 would not be obtained. An evaluation of flow coefficients is presented in more detail in reference 4.

The piston-position-measuring transducer had to be small and light so that it would not affect stability-bleed valve response. Piston position was measured by two strain gages mounted on fingers of a specially designed washer. As the piston opens, the force from the spring deflects the fingers; thus, the strain gages produce a signal proportional to piston position. All 50 stability-bleed valves were made identical, so that they would respond the same way. Then, 16 of the stability-bleed valves also had position-measuring strain gages added to them. The spring-retainer-ring holders (fingered washer) are restrained from rotating by a locating pin. However, this pin did not keep the washer from rotating in all cases of the wind-tunnel testing. Because of the high vibration, some of the washers jumped up on their locating pins. This, in turn, changed the electrical output signals from the strain gages.

Figure 6 shows top and bottom views of an assembled stability-bleed valve. The piston is shown in the partially open position. The top view shows the threaded hole for the adjusting screw for a pair of friction shoes in the stability-bleed-valve centerpost. Turning this screw would make two flat-leaf cantilever springs exert a force on two carbon brake shoes. These in turn would create a friction force on the piston. This feature, however, was not required during the experimental wing-tunnel program.

Figure 7 shows the installation of the throat-bypass stability-bleed system in the YF-12 aircraft flight inlet. One of the stability-bleed valves was replaced by an orifice plate to illustrate a method of bleed-system calibration done during another phase of the experimental program (refs. 13 and 14).

The sensing duct for the forward valve was a tight-fitting rubber tube, as shown in figure 7(a). The sensing duct for the aft stability-bleed valve went from the shield to a manifolded set of ports located just forward of the shock trap. In this case, the metal-tube sensing duct slipped over the short tube extending from the shield. There is a possibility of air leakage at this point.

The reference plenums are indicated in figure 7(b). To save fabrication cost for the wind-tunnel model, these plenums were formed by enclosing a volume between bulkheads in the cowl structure rather than by constructing welded tanks. This created a serious problem when plenum air leaked into the surrounding low-pressure areas, thereby lowering the reference pressure and allowing the stability-bleed valves to open. Two valves were rendered inoperable because of this leakage problem and were replaced by solid plates to simulate closed stability-bleed valves. They were located in compartment 21 forward and 13 aft.

Also shown in figure 7(b) is the connection between the stability-bleed valve and the reference plenum. Because of the tight quarters, it was difficult to get the gasket (between the nut and the stability-bleed valve itself) to seal properly. If this connection is not airtight, stability-bleed valve transient performance is compromised; and if the leak is large enough, it can cause the piston to stay in the full open position.

PROCEDURE

Mechanical characteristics of the stability-bleed valve before, during, and after the wind-tunnel tests were obtained to determine those areas that need further investigation before a flight test. Most of the data presented are steady-state data. However, some transient data, taken during wind-tunnel tests, were included to show the transient performance of the throat-bypass stability-bleed system. The inlet throat-bypass stability-bleed system worked well during the wind-tunnel tests. These results are reported in reference 12.

Before the wind-tunnel tests, the manufacturer mounted the stability-bleed valve on a special holder and measured piston position with a linear variable differential transformer. The data shown in this report are for room temperature. However, considerable work was done at higher temperatures by the manufacturer (refs. 5, 15, and 16; and unpublished data taken in accordance with refs. 15 and 16 for each valve used in the wind-tunnel program). These data consist of piston displacement as a function of pressure drop across the piston and were recorded on X-Y plotters.

During the wind-tunnel tests, the capability of the throat-bypass stability-bleed system to absorb downstream airflow disturbances was investigated with the use of the sliding-plate valves of the disturbance generator. The sliding-plate valves were ramped

closed and then back open again. Ramp rates varying from slower than that required to actuate the stability-bleed valves to the maximum rate of the sliding-plate valves were selected. At each rate, the pulse amplitude was increased until the inlet unstalled. The transient response of the throat-bypass stability-bleed system to an upstream airflow disturbance was also determined. The transient disturbance was introduced by the upstream airflow disturbance device discussed in the APPARATUS section. The disturbance consisted of a change in tunnel flow-field Mach number and flow angularity, as mentioned previously.

After the wind-tunnel tests, two types of steady-state tests were run to obtain the stability-bleed valve mechanical characteristics. One was a test of piston displacement as a function of pressure drop across the piston. The other consisted of measuring this pressure when the piston first opened. The spring-plenum side of the piston was vented to atmosphere. Thus, the pressure drop across the piston was the difference between the applied pressure and atmospheric pressure. The piston displacement as a function of pressure drop was recorded on X-Y plotters.

These steady-state data were obtained while the stability-bleed valves were still mounted in the inlet after the wind-tunnel program. It was done this way to avoid any disturbances after the behavior of the stability-bleed valves relative to their behavior in the wind-tunnel tests. Air was supplied to the bottom of the piston through a rubber tube which was fastened to the bottom of the shield. The pressure in this tube was slowly changed by manually changing a pressure regulator. The pressure was measured with a strain-gage-type transducer which was located near the shield. Stability-bleed valve position was measured by the strain-gage-type arrangement supplied with some of the stability-bleed valves. The traces were repeated several times to check repeatability.

The X-Y plots taken before and after the wind-tunnel tests were used to determine an average value of both friction and effective spring rate for each stability-bleed valve that was equipped with a position transducer. The data are compared in this report.

RESULTS AND DISCUSSION

It should be remembered that while only problem areas of the stability-bleed valve and of the overall system will be discussed, the throat-bypass stability-bleed system did work well for both upstream and downstream airflow disturbances. The information in this report can be used to help to improve the reliability of the stability-bleed valve and the throat-bypass stability-bleed system for future applications.

Transient-Response Data of Throat-Bypass Stability-Bleed System

Figure 8 shows the transient response of the throat-bypass stability-bleed system to a downstream airflow disturbance. These transient responses are typical of the data which were taken at Mach 2.5. The figure shows responses to a slow and a fast disturbance ramp rate, with the forward-bypass-door shock-position control operational.

Figure 8(a) shows that not all of the stability-bleed valves opened fully or at the same rate. Only the stability-bleed valves in compartments 1, 4, and 7 opened fully. Since the inlet was set at zero angles of attack and sideslip, one might have expected that all the stability-bleed valves would have opened about the same. However, several factors can cause nonuniformity of stability-bleed-valve response. First, nonuniform pressures in the inlet during the disturbance transient can be a factor. A second factor is inequality of stability-bleed valve characteristics such as piston friction, spring preload, spring rate, or internal leakage. A third factor is leakage from other parts of the throat-bypass stability-bleed system. In fact, additional transient-pressure traces showed that the cowl static-pressure variation in the region of aft-compartment 13 was only about half as much as that for the other aft compartments in the inlet. Thus, the main reason that the stability-bleed valve in aft-compartment 13 did not open as much as the others was that there was not a large enough pressure increase to cause it to do so. The reason for the other stability-bleed valves not having opened or closed at the same rate was probably a combination of the factors mentioned.

The position trace for the stability-bleed valve in compartment 1 shows that the valve went full open and then full closed. Since these were physical stops, the stability-bleed-valve piston could not have been overshooting as the trace shows. The indicated overshoot resulted from sensitivity of the position transducer to the impact of the piston as it hits the physical stops. This ringing effect is more clearly seen at the faster chart speed used in figure 8(b). Another problem with the position transducer was that both its gain and its steady-state output tended to drift.

Figure 8(b) shows the transient-response traces for a fast disturbance ramp rate. For this faster disturbance rate, the shock-position-control system is much less effective. This is illustrated by a comparison of the forward-bypass-door traces in figures 8(a) and (b). It is also indicated by the difference in disturbance amplitudes before unstart for the two disturbance rates.

Figure 9 shows the inlet transient response to an upstream airflow disturbance produced by the gust generator. In this case, the disturbance was applied and held, as evidenced by the step increase in spike-tip total pressure. The stability-bleed-valve trace is from a forward compartment, since an upstream airflow disturbance increases the cowl-surface static pressure mainly in that region where the forward row of stability-bleed valves was located. Initially, the valves compensate for the disturbance and keep

the inlet started. However, the valves gradually close, and the inlet static pressure increases until, finally, the valves are no longer compensating for the disturbance and the inlet unstarts. The increased noise on the stability-bleed valve position trace after the inlet unstarts results from the sensitivity of the position transducer to the increased vibration after inlet unstart. With the stability-bleed valves working, the inlet remained started for about 1.25 seconds. When the stability-bleed valves were locked closed, the inlet remained started for only 0.30 second (ref. 12). The additional second that the stability-bleed valves keep the inlet started is enough time to get the spike or the forward-bypass door to move, thus keeping the inlet started for this disturbance.

Stability-Bleed-Valve Mechanical-Characteristic Data Obtained Before and After the Wind-Tunnel Tests

Valve opening pressures. - Figure 10 shows the steady-state opening pressures across the pistons of the stability-bleed valves before and after the wind-tunnel tests. The opening pressure is the pressure that just starts to move the piston from its fully closed position. Both the compartment numbers and the valve serial numbers are given so that these data could be referenced in the future, should these stability-bleed valves be used again. The data indicate that in general the opening pressures were lower after the wind-tunnel tests than they had been before the tests. This change in opening pressure suggests that the effective spring rate, the spring preload, or the friction on the piston had decreased. (This will be discussed in more detail in the next section.) A small portion of this difference can be ascribed to gravity effects. The orientation of the stability-bleed valves was such that for the valve in compartment 13, gravity was in the same direction as the applied pressure, thus reducing the pressure required to start opening the valve; for the stability-bleed valve in compartment 1, gravity was in the opposite direction to the applied pressure; for the stability-bleed valves in compartments 7 and 19, gravity was perpendicular to the applied pressure. The pressure equivalent of the piston weight divided by its area is only 0.023 N/cm^2 , so the required correction would be small. Even though there was a decrease in friction, spring preload, or effective spring rate, the transient traces of stability-bleed-valve position during inlet operation did not show any signs of stability-bleed-valve instability.

Valve hysteresis and spring-rate characteristics. - Figure 11 shows an idealized hysteresis plot for a stability-bleed valve. The arrows show the trajectory of piston displacement as a function of the force applied to the piston. The dashed line represents the action of a frictionless valve. The solid lines show the action of a stability-bleed valve with friction. As the applied force is increased, the piston breaks loose at point 1. The stability-bleed valve opens linearly until it reaches full stroke at point 2. As the

force is reduced, the stability-bleed valve breaks loose at point 3 and closes linearly to point 4, where it is fully closed.

In the case of the stability-bleed valves, the breakaway friction did not exceed the running friction. Thus, trajectories like that shown by the dotted line at point 1 did not occur.

As indicated by the triangle, the ratio of the change in force across the piston to the change in piston displacement is equal to the effective spring rate. In the ideal case, the effective spring rate would be equal to the actual spring rate. However, in the case of these stability-bleed valves, there are other effects which also help to determine the slopes of the curves. This will be discussed later in this section when actual data are presented.

Figure 12 shows the hysteresis plots taken before and after the wind-tunnel tests for three representative stability-bleed valves of the throat-bypass stability-bleed system. Figure 12(a) shows that the friction was not constant in each direction of piston motion. Therefore, the effective spring rate in each direction is different. This change in effective spring rate did show up in all three sets of data shown in figure 12.

The plots of figure 12 also show that piston friction decreased during the wind-tunnel program. One possible explanation might be the smoothing effect of the piston rings on the rough surfaces that were left from the manufacturing process. However, this smoothing process had already been started when the stability-bleed valves were cycled before data were taken by the manufacturer. At present, the actual cause of this decrease in piston friction is not known.

It is noted that none of the plots show signs of classical stiction. This would show up in the lower right or upper left corners of the hysteresis plots. The absence of stiction must be the result of the particular combination of materials used for the piston sleeve bearing, the piston rings, and the housing and centerpost.

The hysteresis-characteristic data for 15 stability-bleed valves are summarized in table I. Listed in the table are the values of valve-closing effective spring rate, valve-opening effective spring rate, and valve friction obtained for each stability-bleed valve before and after the wind-tunnel tests. The table also shows the change in the friction of each stability-bleed valve from before to after the wind-tunnel tests. Finally, the 15-valve average for each of these items is also given in the table. The data show that the average effective spring rate in both the opening and closing directions decreased by about 25 percent during the wind-tunnel tests, and the average friction decreased by about 20 percent. However, the stability-bleed-valve parts did not show any signs of wear problems, and the valves did perform well during the wind-tunnel tests.

One matter of concern about friction did show up during the manufacturer's high-temperature bench tests of the prototype stability-bleed valve. Since the wind-tunnel tests were run at lower temperatures, the problem did not occur during wind-tunnel

testing of the throat-bypass stability-bleed system. At 700 K, and after more than 30 000 opening and closing strokes, a bench-test stability-bleed valve stuck open. When the valve was disassembled and reassembled at room temperature, the friction returned to its initial lower room-temperature value. This large increase in friction seems to be a function of both temperature and of the number of strokes by the stability-bleed valve. Perhaps the carbon material of the piston sleeve bearing had picked up (at room temperature) some moisture or other foreign material which then boiled off and/or wore off during the many cycles at 700 K and thereby reduced the lubricating qualities of the carbon bearing. This hypothesis is supported in the literature on bearing materials (refs. 17 to 19). This problem could be alleviated with use of a different material for the piston rings and sleeve bearing. The current material, however, could be used for an experimental flight program that would evaluate the effectiveness of the throat-bypass stability-bleed system on inlet operation or for additional wind-tunnel tests.

Additional Observations of Stability-Bleed-Valve Mechanical Characteristics

Distortion of the stability-bleed valve mounting surface may have caused a piston to bind during one part of the wind-tunnel program. When the inlet was inspected after a wind-tunnel run, one stability-bleed valve was found open. The valve snapped shut when one of its mounting screws was loosened. During the static tests after the wind-tunnel program, attempts were made to duplicate this piston-binding problem, but the attempts were unsuccessful. Loosening of mounting screws on other stability-bleed valves did not significantly affect their hysteresis characteristics during the static tests. For a flight application, care should be taken to design the stability-bleed-valve mounting flanges and the body so as to prevent mechanical distortions of the inlet structure which could induce erratic valve operation. Also, the stability-bleed valve and inlet mounting surfaces must be flat and parallel to minimize airflow leakage.

As was mentioned previously, during a research or development phase of a program for the throat-bypass stability-bleed system, it would be desirable to measure piston position on a number of stability-bleed valves in order to evaluate the system. Figure 13 shows the position-transducer arrangement. The strain gages measure the force in the spring, which indicates piston position, and put out an electrical signal proportional to valve piston position. In addition to the problems mentioned previously, the position transducer had one other problem. Inspection of the stability-bleed valves after the wind-tunnel program revealed that some of the arms which hold the spring retainer ring were bent. Figure 14 shows undamaged and damaged arms. The present configuration may be suitable, but the materials and the heat treatment of the arms may require some changes to enable the arms to withstand the tunnel testing. Additional testing and evaluation of these arms is necessary.

In flight, the stability-bleed valves would be subjected also to forces due to random vibration and/or the maneuvers of the aircraft. This factor was not investigated in the wind-tunnel studies. With the present stability-bleed-valve design, if initially there were no pressure drop across the piston, it would take an acceleration of about 10 g's in the opening direction to overcome the friction force and the spring preload force on the piston and cause the piston to start to open. If the piston were initially moving in the opening direction, it would take an acceleration of about 5 g's in the closing direction to cause the piston to start to close. This is equivalent to twice the friction force on the piston. These g levels exceed those to which the YF-12 aircraft flight inlets would be expected to be subjected either from random vibration or from aircraft maneuvers. However, in future redesigns of stability-bleed-valve piston rings and sleeve bearings, the friction should not be reduced to the point where the ratio of friction to piston mass would be so low as to cause valve sensitivity to such forces.

Air Leaks Affecting Performance of Stability-Bleed Valve and Throat-Bypass Stability-Bleed System

The throat-bypass stability-bleed system described herein relies on trapped air pressure to actuate the stability-bleed valves. Therefore, it is imperative that the system be free of any air leaks that might affect the operation of the valves. An air leak can cause a stability-bleed valve to remain closed or to remain open, depending on the location of the leak.

The modifications made to the inlet for the wind-tunnel tests of the throat-bypass stability-bleed system were strongly influenced by the need to keep fabrication costs to a minimum and to provide the flexibility for testing various bleed configurations. As a result, the system suffered from air-leakage problems, despite the considerable effort made to prevent them. The following is a discussion of those leaks that caused trouble during the wind-tunnel tests.

Stability-bleed valve designs should avoid or minimize the need for openings into the spring plenum (which is actually the reference-pressure plenum of the valve). Such openings increase the chance of sealing problems and, therefore, the risk of air leaks. Figure 6(b) shows two such openings: the position-transducer locating-pin hole, and the friction-shoe adjusting-screw hole. On some valves, the epoxy material used to seal the locating-pin hole came off during the wind-tunnel tests.

As mentioned previously, the reference plenums were formed by enclosing volumes between bulkheads in the cowl structure. This approach created leakage problems. Therefore, to prevent air leaks, each reference plenum should be constructed as a chamber, or tank, with all welded seams and joints.

It is also important that the bulkhead between the forward and aft stability-bleed-valve compartments not permit any leaks. These compartments separate bleed flows from two different portions of the inlet; one responds to upstream disturbances, and the other responds to downstream disturbances. A leak between these two compartments would decrease the performance of the bleed system by allowing recirculating airflow between the two bleed regions.

Care should also be taken to see that there will not be any leaks at the connecting points of the sensing duct. In particular, leaks can occur where the duct connects to the stability-bleed-valve shield. A pressure leak here could affect the pressure on the underside of the piston and, thus, the piston motion.

For an experimental flight system, safety may require the use of an override system to pressurize the reference plenums and force the stability-bleed valves closed. This would require a very tight pressurizing system, so that when it is not activated, the high-pressure air would not leak into the reference plenums.

CONCLUDING REMARKS

Results of static bench evaluation tests conducted before and after a wind-tunnel program on a set of 50, mechanical, self-acting, stability-bleed valves are presented. The stability-bleed valves are located at the exits of porous bleed regions in the cowl wall ahead of the throat of a full-scale, YF-12 aircraft inlet. The function of the stability-bleed valves is to reduce bleed airflow during on-design operation of the inlet but to open quickly when inlet unstart is impending. Operation of the throat-bypass stability-bleed system during its evaluation in the wind tunnel was highly satisfactory.

The stability-bleed valves were designed to be flight tested in the inlet of the YF-12 aircraft at its cruise Mach number. For that reason, great care was exercised in the design of the valve and in the testing of a prototype valve to ensure that the valve would function properly during the experimental flight program. However, the design of the rest of the throat-bypass stability-bleed system did not receive the same amount of effort and attention to detail, since it was meant to be used for only the wind-tunnel tests, where the temperatures are much lower than those encountered during flight. The wind-tunnel system also had to be more flexible than a flight system, so that several model configurations could be investigated before one were selected for flight testing.

No serious mechanical problems of the stability-bleed valves were revealed by the wind-tunnel tests. However, the following are some comments regarding the valves:

One concern is an increase in piston friction discovered during high-temperature bench tests conducted by the manufacturer. The large increase in friction seems to be a function of both temperature and of the number of piston strokes. This problem could be

alleviated with the use of a different material for the piston rings and sleeve bearing. However, the current material could be used for an experimental flight program.

The friction drag of the 15 stability-bleed valves that were fitted with position transducers decreased about 20 percent during the wind-tunnel program. The stability-bleed-valve parts did not show scoring or wear problems. Even with this decrease, the valves performed quite well during the wind-tunnel tests.

Accelerations between 5 and 10 g's could affect stability-bleed-valve piston motion. These g levels exceed those expected for the YF-12 aircraft flight-inlet environment. The sensitivity of the stability-bleed valves to acceleration forces was not evaluated during the wind-tunnel tests.

Air leaks from the reference-pressure side of the piston could be a problem. Future stability-bleed-valve designs should avoid or minimize the presence of openings that can cause such leakage.

The springs used in the stability-bleed valves tested in the wind tunnel may not be suitable for long-term use. For the 15 stability-bleed valves that had position transducers, the average value of the effective spring rate decreased by about 25 percent during the wind-tunnel tests.

Distortion of the stability-bleed-valve mounting surface may have caused a piston to bind at one point during the wind-tunnel program. For a flight application, care should be taken to design the stability-bleed-valve mounting flanges and the valve body so that mechanical distortions of the inlet structure will not induce erratic valve operation.

A piston-position transducer design or redesign is needed for either wind-tunnel or flight-test programs. The strain-gaged, cantilever-beam position transducer used in the wind-tunnel program was basically satisfactory, but it needs improvements in beam materials and/or configuration and in the method of restraint.

Comments regarding the other components of the throat-bypass stability-bleed system concern the fact that the system suffered from problems of air leakage. Since this system relies on sealed air chambers for proper activation of the stability-bleed valves, air leakage can cause the valves to bleed continuously or to remain closed, depending on the location of the leak. Use of welded reference-pressure tanks and good connections for the pressure sensing lines will eliminate these problems. The bleed plenums should also be airtight, except for their inlets and exits, so that airflow recirculation problems can be avoided. For an experimental flight system, safety may require the use of an override system to pressurize the reference plenums and force the stability-bleed valves closed. This would require a very tight pressurizing system.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 30, 1976,
743-03.

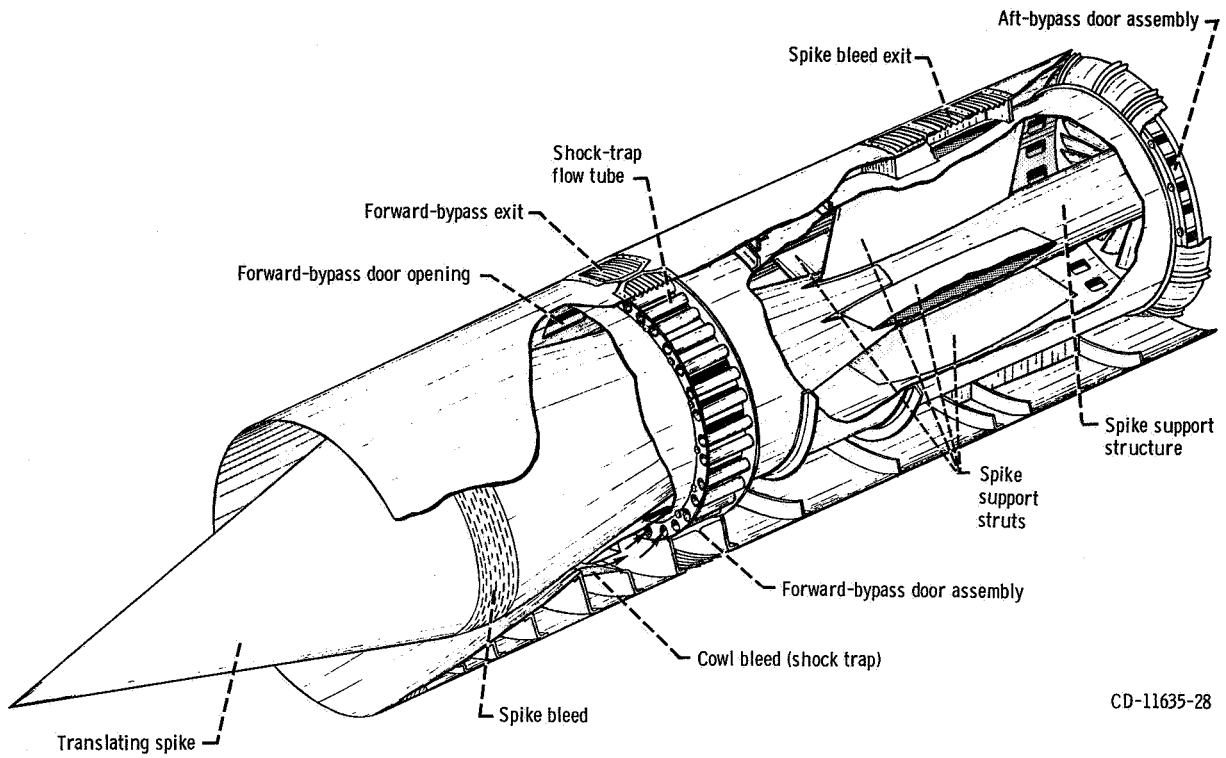
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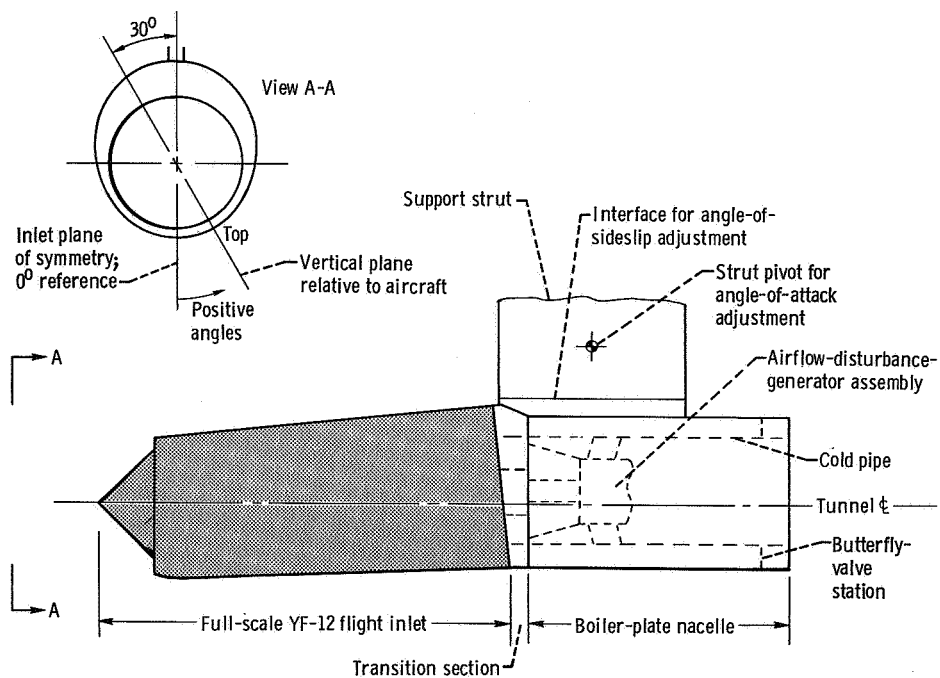
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TABLE I. - STABILITY-BLEED VALVE EFFECTIVE SPRING RATES AND FRICTION BEFORE AND AFTER
WIND-TUNNEL TESTING

Compartment number	Before wind-tunnel testing			After wind-tunnel testing			Change in friction, N/cm ²
	Effective spring rate, N/cm		Friction amplitude, N/cm ²	Effective spring rate, N/cm		Friction amplitude, N/cm ²	
	Closing	Opening		Closing	Opening		
Forward:							
1	4.1	5.0	0.075	3.4	3.1	0.077	+0.002
4	3.7	4.3	.074	2.6	2.6	.055	-.019
7	3.8	3.9	.077	3.8	4.0	.079	+.002
10	4.0	5.0	.079	2.6	3.2	.064	-.015
13	3.8	4.1	.086	3.4	2.9	.059	-.027
16	4.3	4.7	.075	3.2	3.3	.072	-.003
19	5.0	4.6	.084	4.2	3.3	.075	-.009
23	4.9	4.1	.088	3.5	2.8	.078	-.010
Aft:							
1	4.0	4.5	0.086	2.9	3.4	0.058	-0.028
4	3.0	5.0	.076	3.1	3.0	.063	-.013
7	3.9	3.7	.076	2.5	3.0	.048	-.028
10	4.9	4.3	.086	3.6	3.2	.065	-.021
16	3.2	4.5	.086	3.0	3.1	.071	-.015
19	4.3	3.3	.088	3.2	3.1	.057	-.031
23	5.0	3.6	.094	3.3	2.2	.059	-.035
Average	4.1	4.3	0.082	3.2	3.1	0.065	-0.017

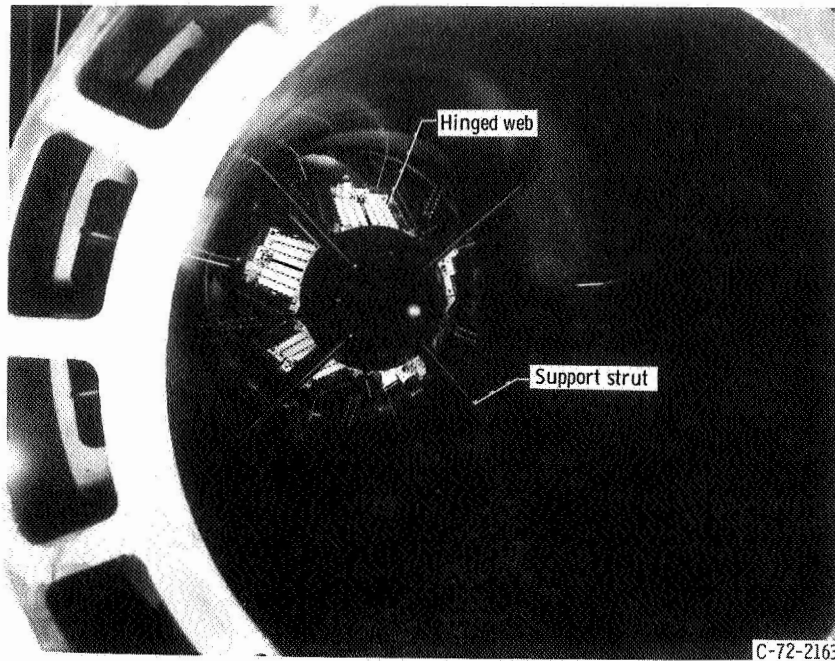


(a) Isometric view of inlet.

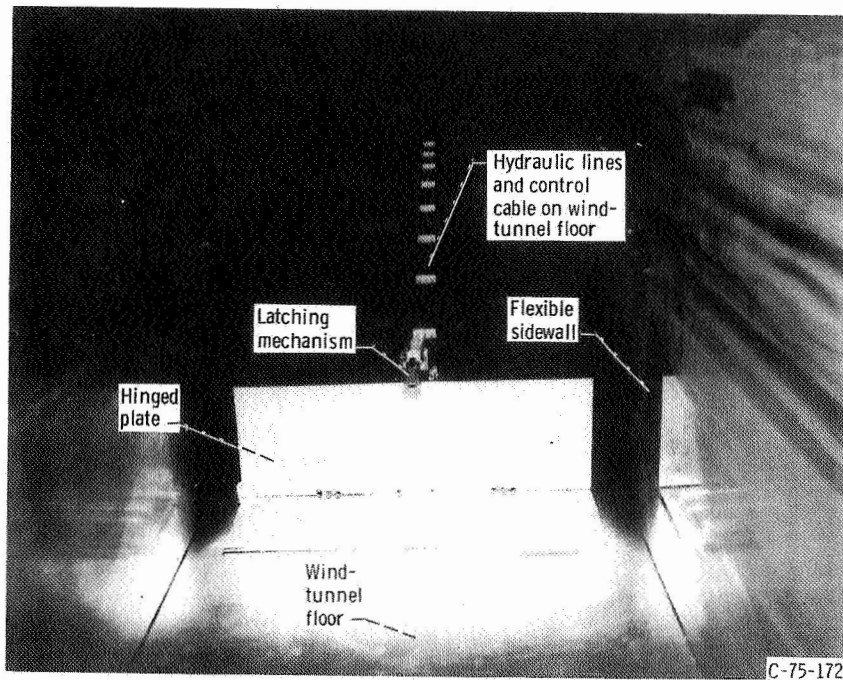


(b) Schematic of inlet and cold-pipe assembly.

Figure 1. - YF-12 aircraft flight inlet as tested in 10- by 10-Foot Supersonic Wind Tunnel.



(a) Downstream airflow-disturbance-generator assembly installed in cold pipe and expanded about halfway. (View looking upstream from aft end of cold pipe.)



(b) Upstream airflow-disturbance device, or gust generator, located at geometric throat of wind-tunnel nozzle. (View looking upstream.)

Figure 2. - Airflow-disturbance devices used for wind-tunnel tests of stability-bleed system.

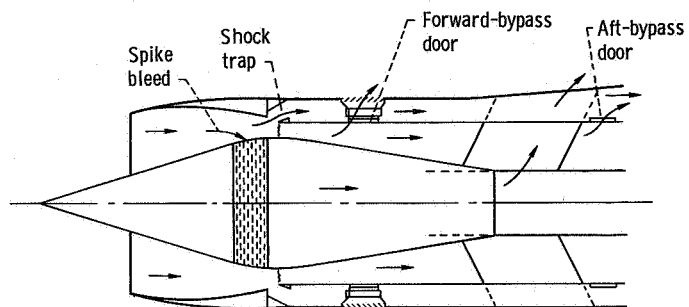
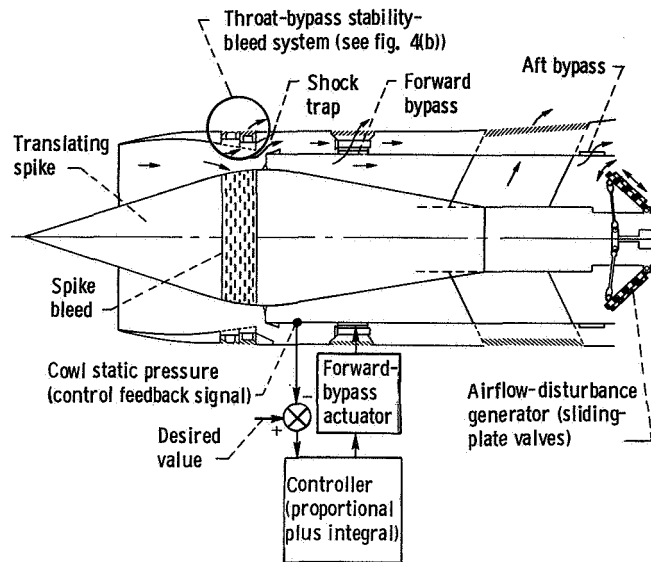
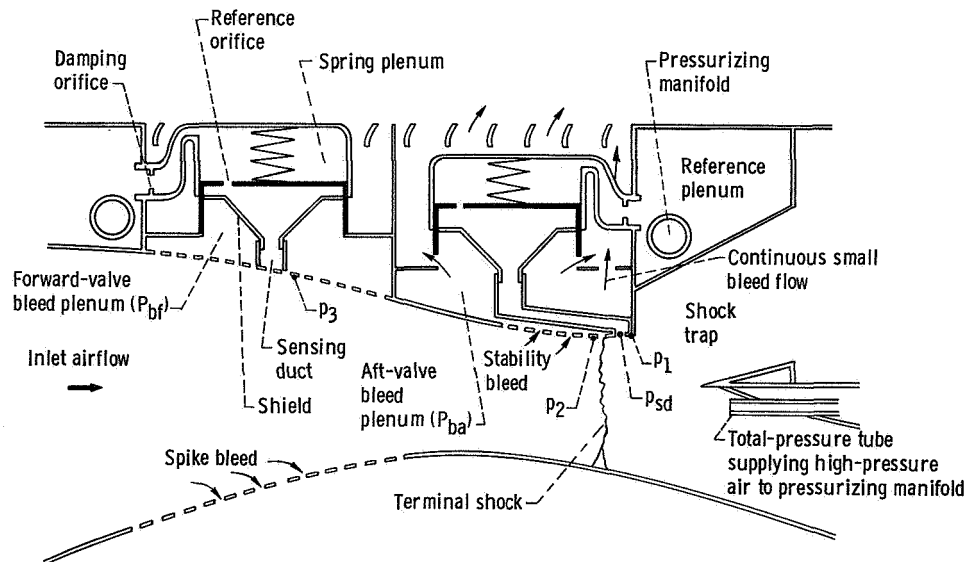


Figure 3. - Airflow systems of YF-12 aircraft inlet.

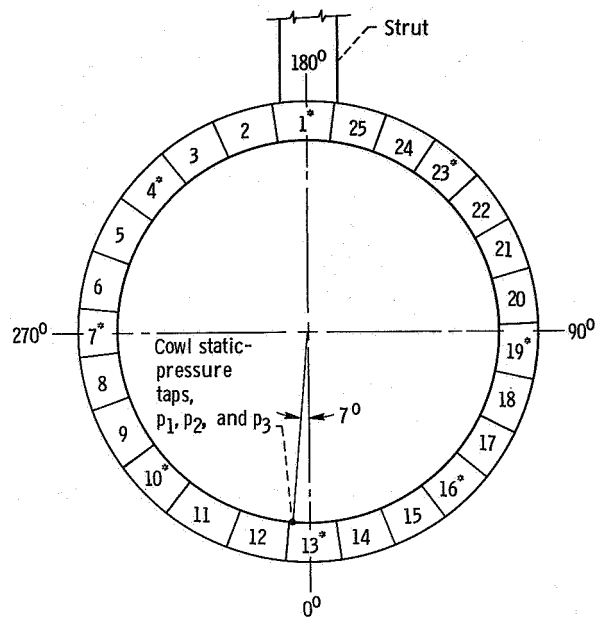


(a) Schematic of inlet, bleeds, bypasses, and throat-bypass stability-bleed system.



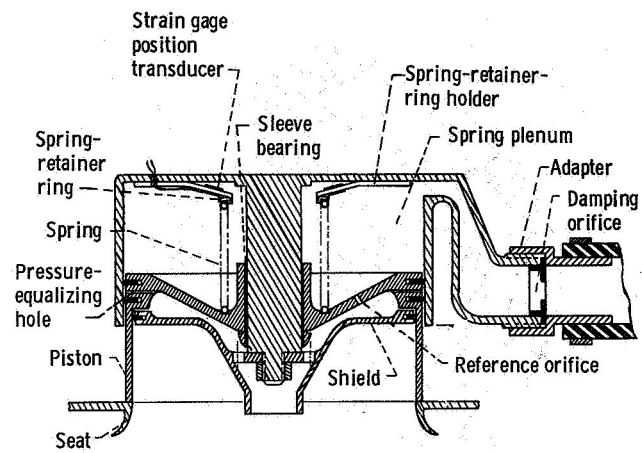
(b) Detailed schematic of throat-bypass stability-bleed system.

Figure 4. - Throat-bypass stability-bleed system in the YF-12 aircraft flight inlet.

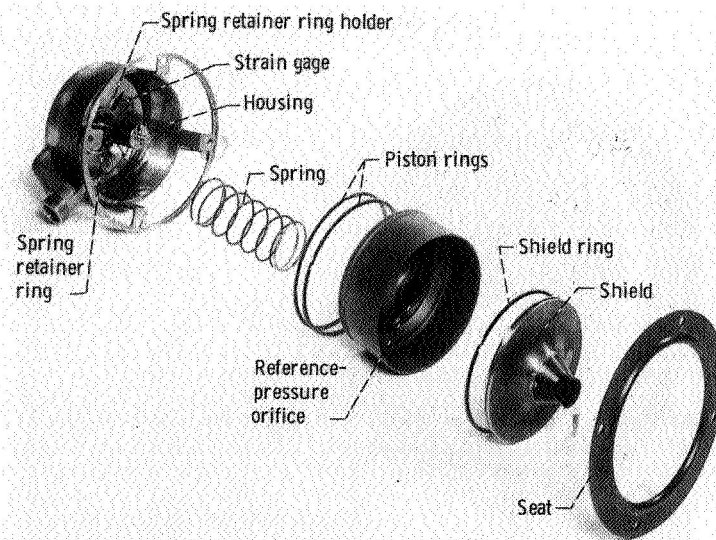


(c) Stability-bleed valve compartment identification (view looking downstream). Asterisks denote compartments wherein valves with position transducers are located.

Figure 4. - Concluded.



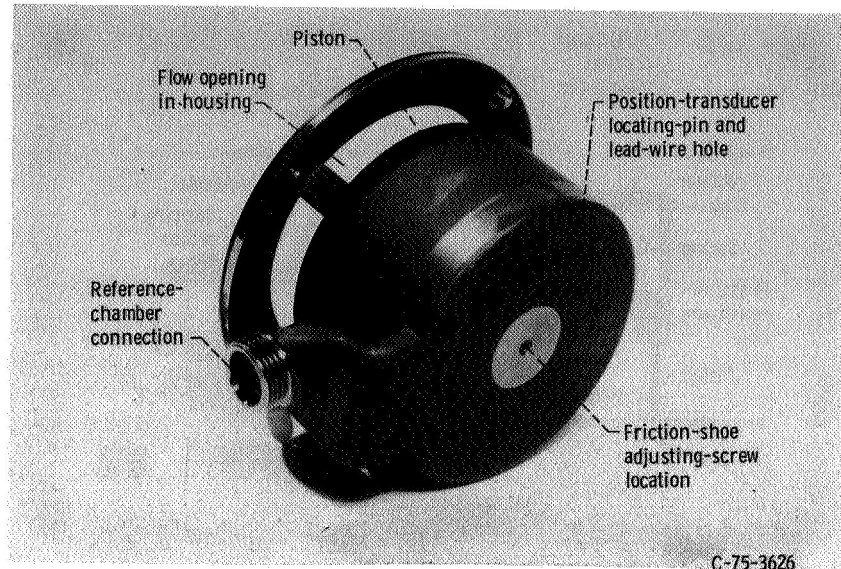
(a) Cross section.



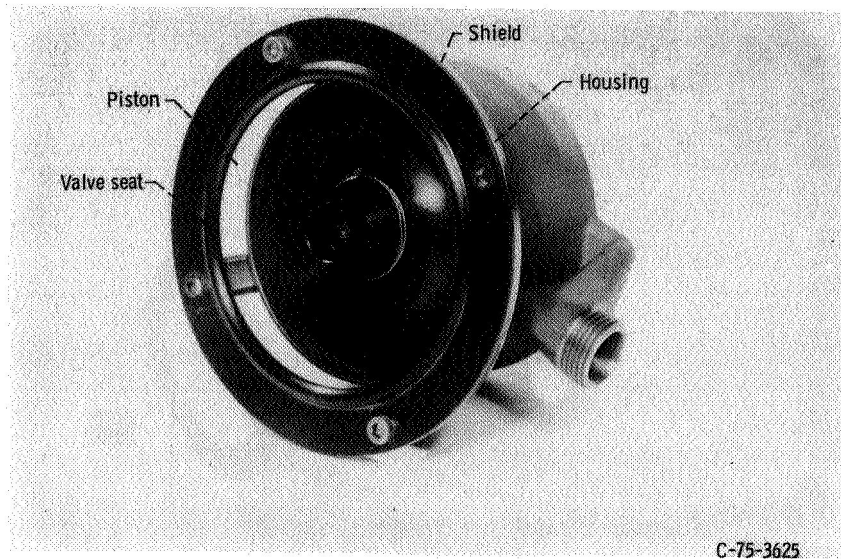
(b) Exploded view

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Figure 5. - Stability-bleed valve.

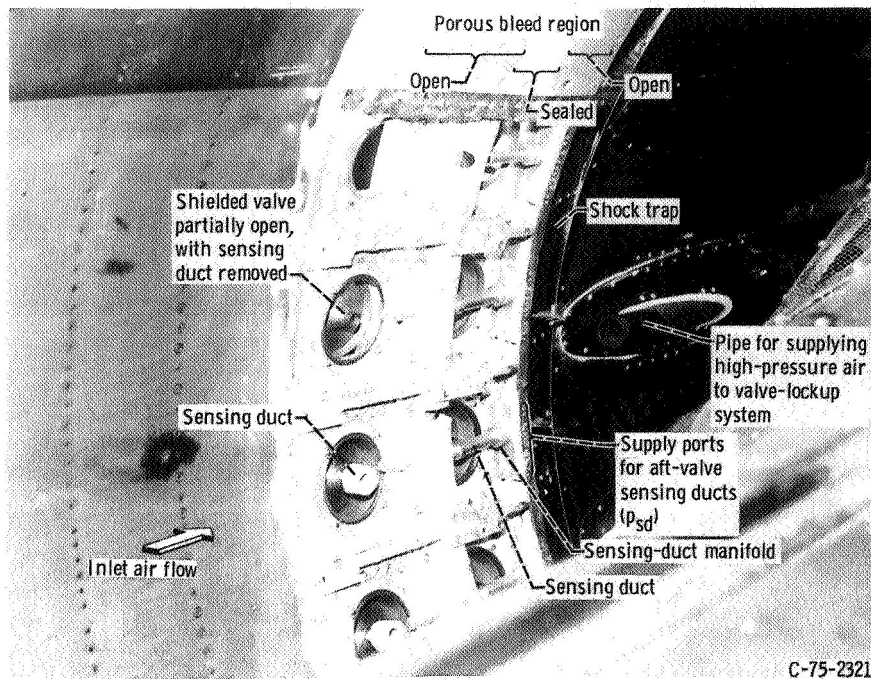


(a) Top view.

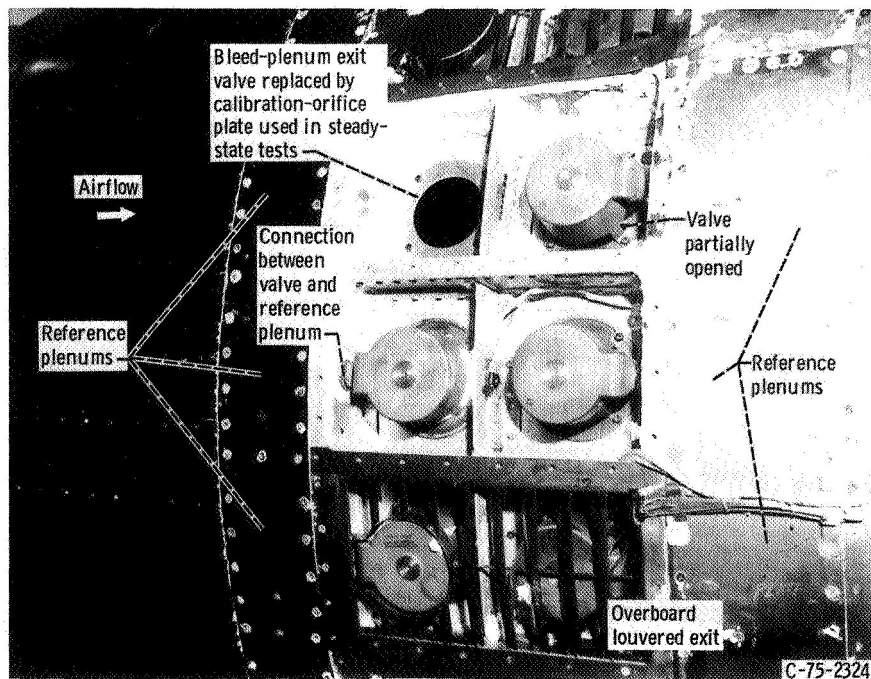


(b) Bottom view.

Figure 6. - Stability-bleed valve assembled.

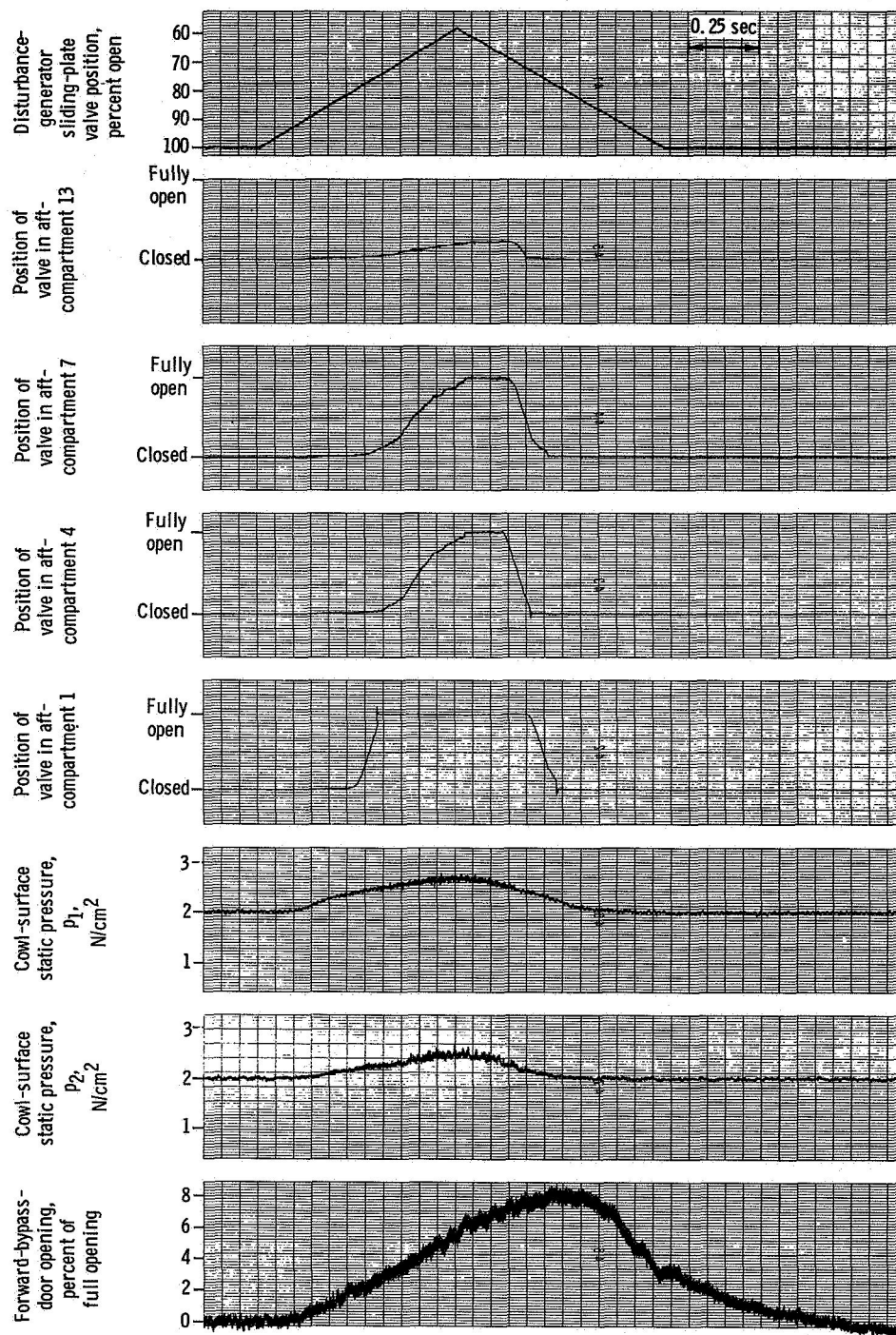


(a) Internal view. (Spike and portion of porous wall removed for clarity.)



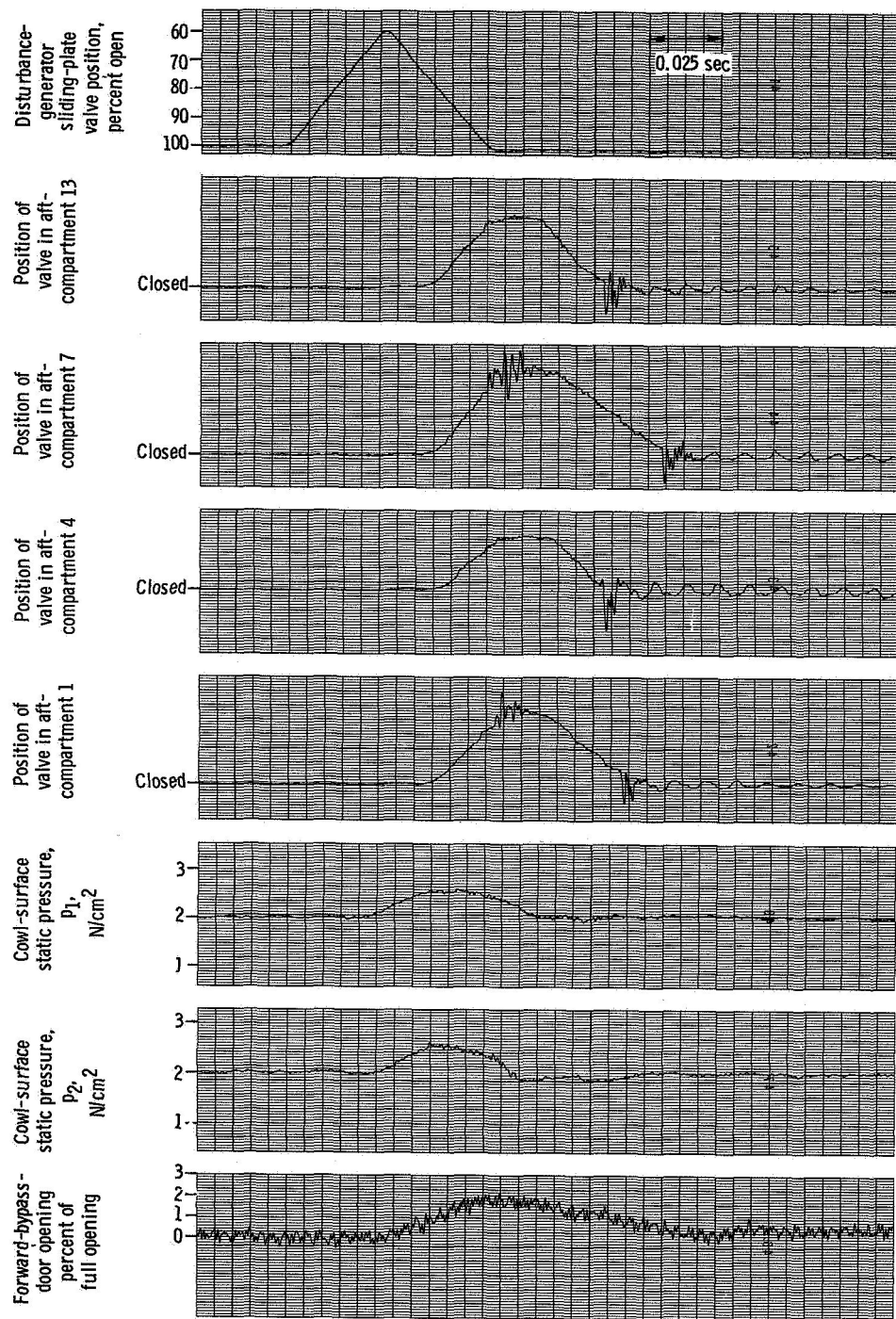
(b) External view. (Some of overboard-exit louvers removed for clarity.)

Figure 7. - Installation of throat-bypass stability-bleed system in cowl of inlet.



(a) Slow disturbance. Amplitude, 17.73 kg/sec; rate, 25.57 (kg/sec)/sec.

Figure 8. - Response of throat-bypass stability-bleed system to slow and fast downstream airflow disturbances. Spike-tip Mach number, M_0 , 2.47; inlet local angles of attack and sideslip, α_l and β_l , both zero.



(b) Fast disturbance. Amplitude, 17.22 kg/sec; rate, 512.1 (kg/sec)/sec.

Figure 8. - Concluded.

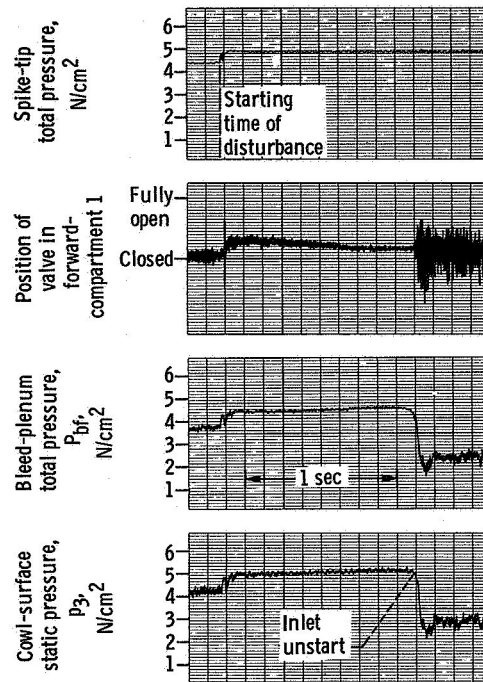
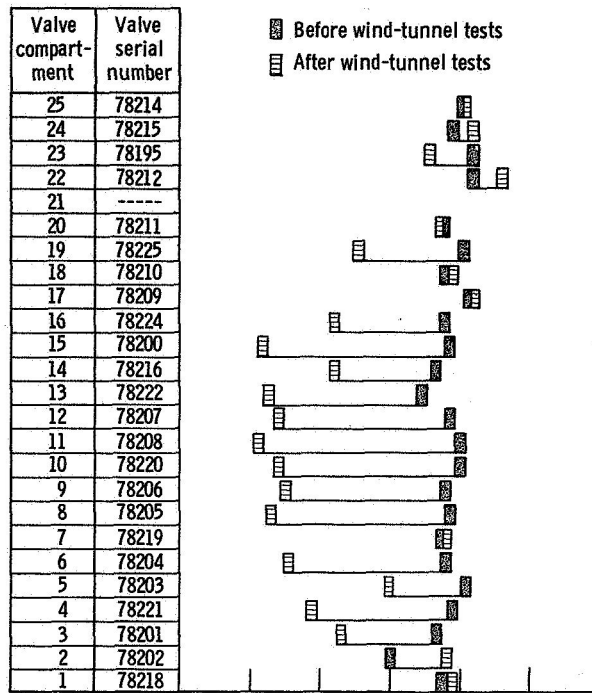
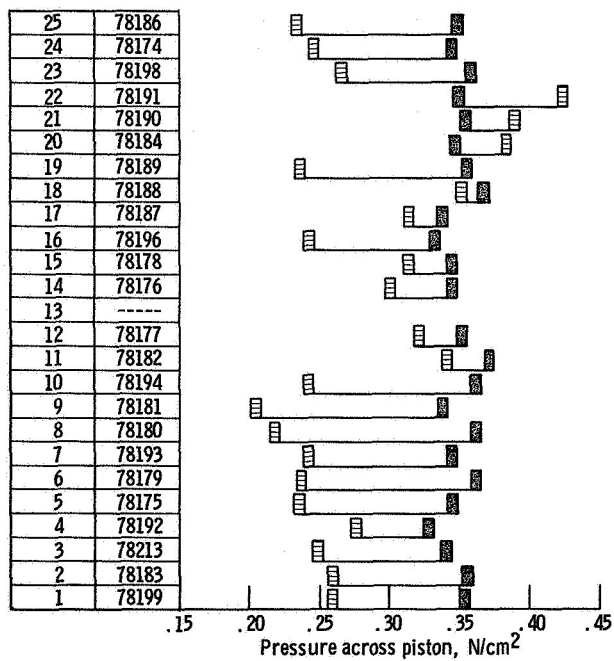


Figure 9. - Response of throat-bypass stability-bleed system to an upstream airflow disturbance. Spike-tip Mach number was 2.55 before disturbance, and 2.4 after; spike-tip angle of attack was zero before disturbance, and 2.4° after.

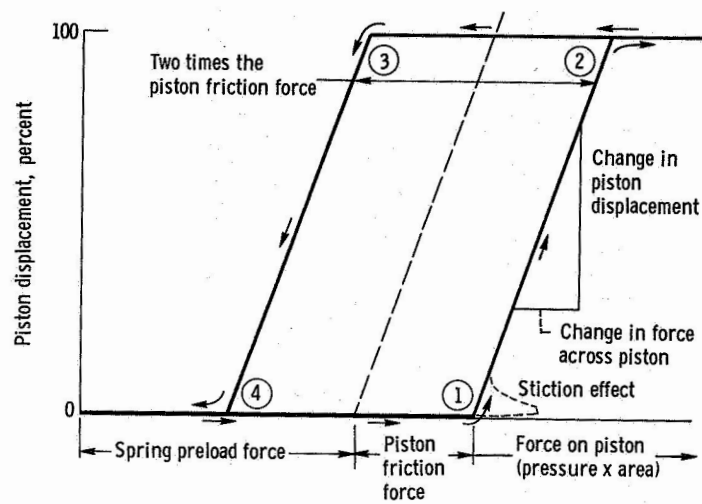


(a) Forward valves.



(b) Aft valves.

Figure 10. - Steady-state initial opening pressures of the stability-bleed valves before and after the wind-tunnel tests.



$$\text{Effective spring rate} = \frac{\text{Change in force across piston}}{\text{Change in piston displacement}}$$

Figure 11. - General hysteresis plot for a stability-bleed valve.

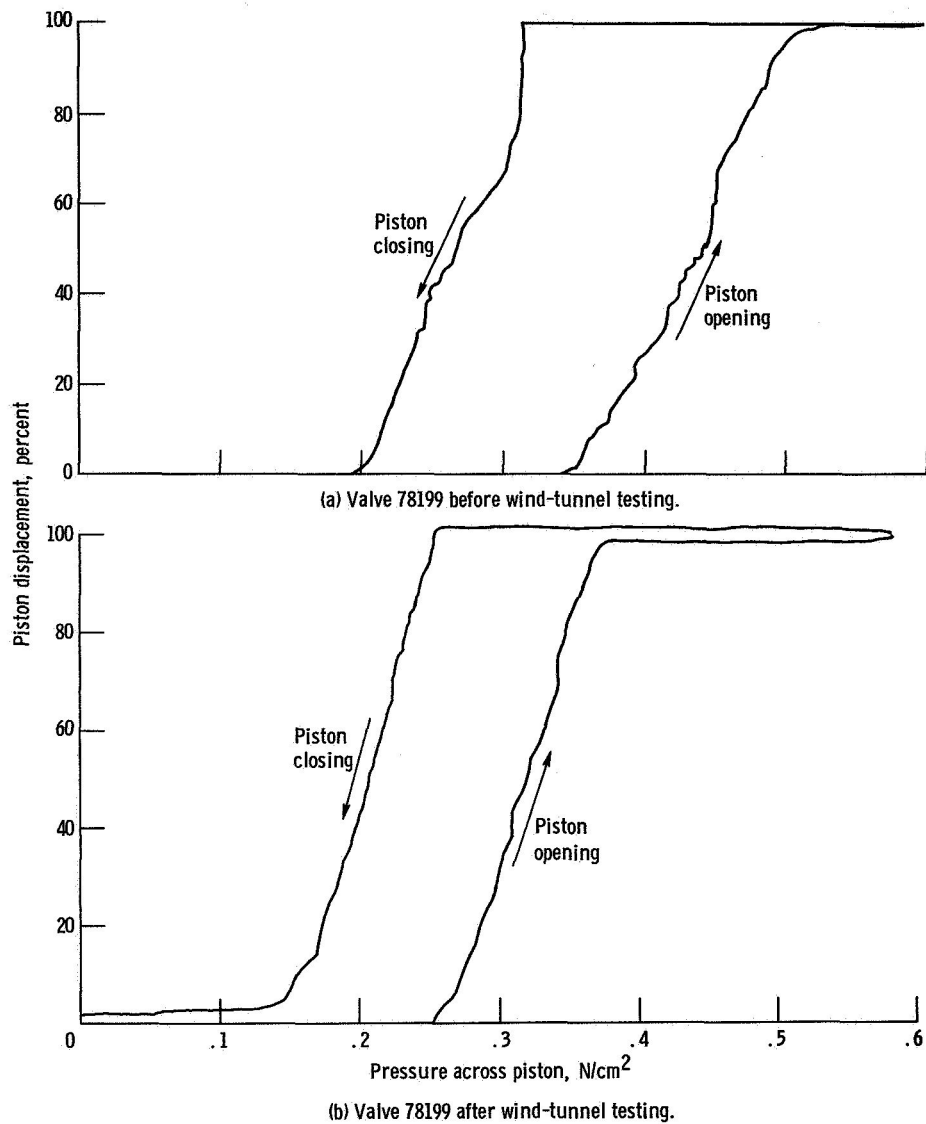
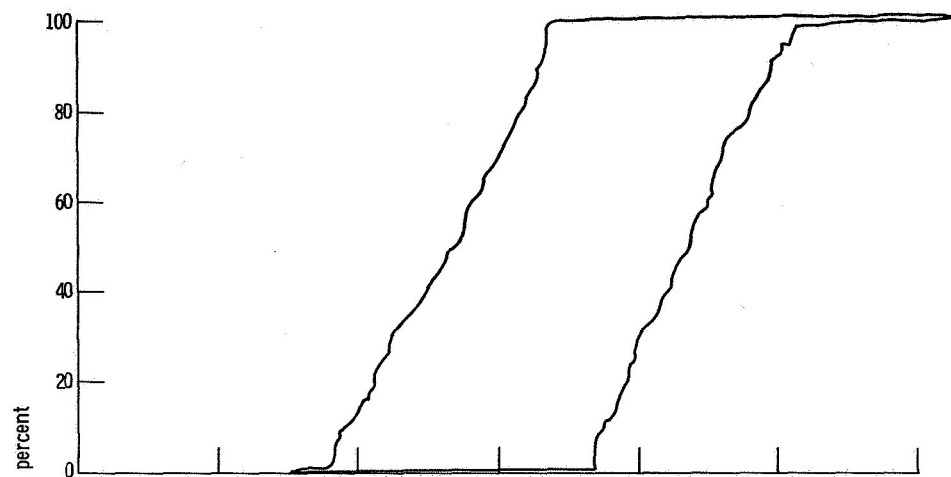
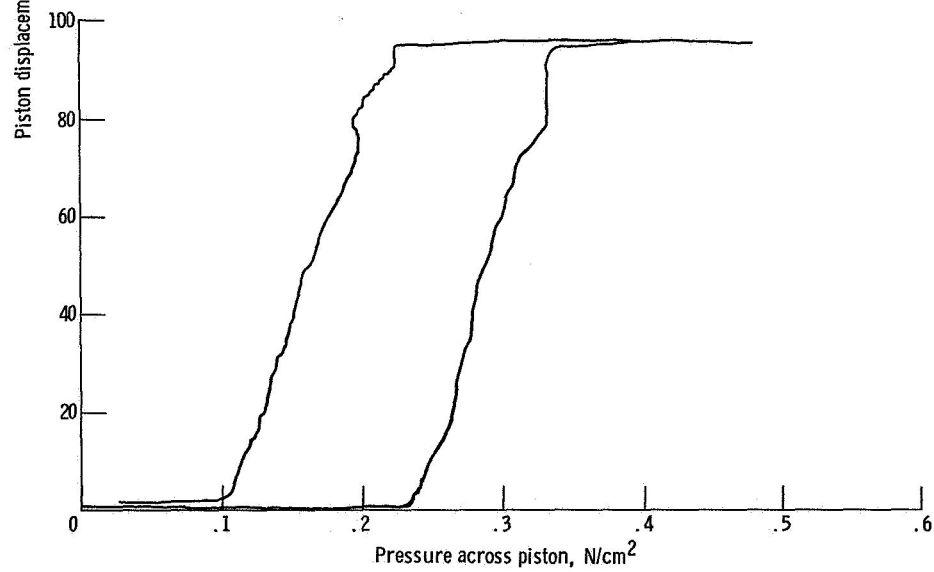


Figure 12. - Plots of valve stroke as function of pressure across piston (friction hysteresis loop) for three typical stability-bleed valves before and after wind-tunnel tests.



(c) Valve 78194 before wind-tunnel testing.



(d) Valve 78194 after wind-tunnel testing.

Figure 12. - Continued.

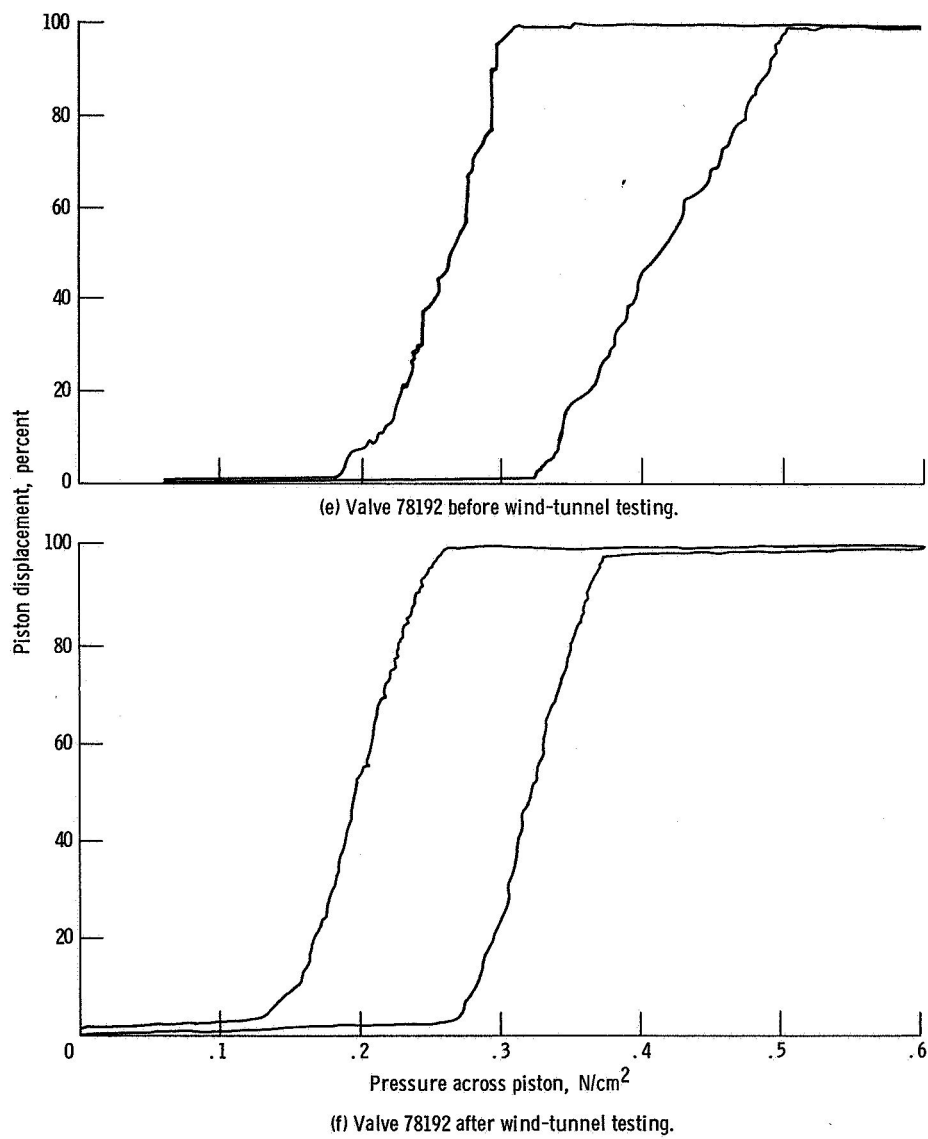


Figure 12. - Concluded.

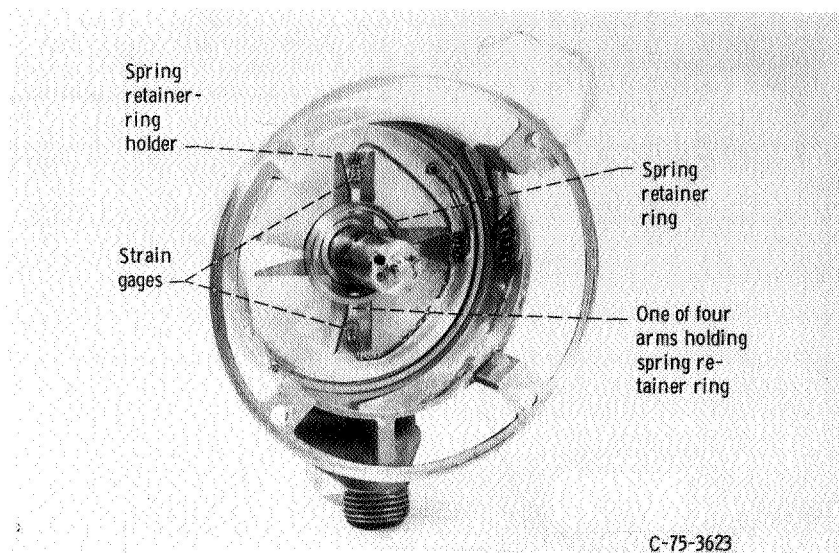


Figure 13. - Strain-gage and spring-retainer-ring arrangement.

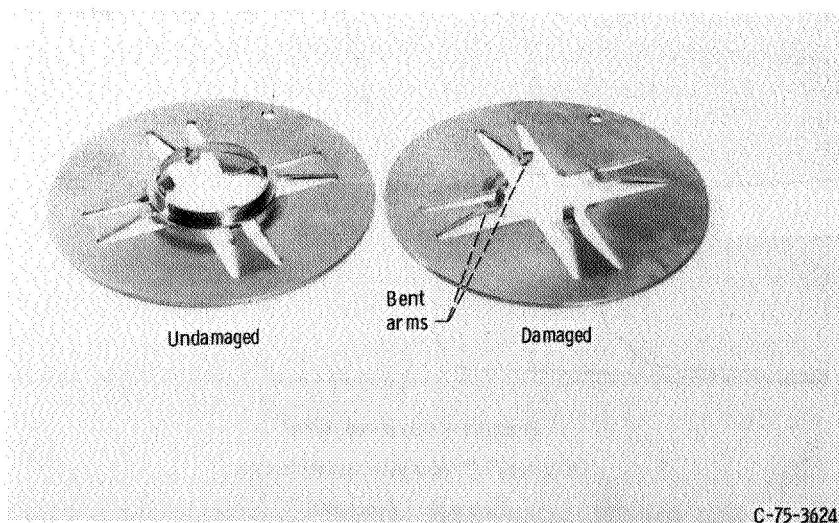


Figure 14. - Undamaged and damaged arms that hold the spring-retainer ring.



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